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MAGNETIC FLUID CUSHIONING DEVICE FOR A FOOTWEAR OR SHOE

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BACKGROUND OF THE INVENTION

[0001] The present invention is generally directed to footwear or shoes, and more particularly to a cushioning device for a footwear or shoe including a magnetic fluid for absorbing and dampening vibrations and shocks.

[0002] Magnetic fluids typically include magnetic field responsive fluids containing magnetizable particles dispersed in a liquid carrier. These fluids typically have been used in devices, such as dampers, shock absorbers, seals, valves and the like to provide varying stress levels controlled by an external magnetic field. The variable stress is created by magnetic coupling of the particles in the form of chains or bent wall-like structures upon interaction

with an external magnetic field. As to the composition, these fluids are typically include micron-sized or nano-sized particles dispersed in an engineering medium, such as hydraulic oil, mineral oil, or water, or the like.

[0003] A shoe typically consists of two parts, an upper and a sole. The upper encloses the foot and the sole contacts the ground and provides the wearer with support and protection of the foot. The sole may contact the ground with considerable force, therefore, the sole must act as a shock absorber and consist of an energy absorbent material. Shock absorption on impact is considered to be one of the most important factors in foot and knee injuries sustained by runners and joggers. In addition, injuries are also sustained from activities such as basketball, volleyball, and aerobics due to both forefoot and rearfoot impacts.

[0004] The use of elastomeric foams, such as ethylene vinyl acetate (EVA) foam, gas chambers in a foam midsole, gel filled cushioning elements, and springs to absorb shock and support and cushion the foot, is well known in the art. In addition, prior art discloses shoe soles or inserts for the sole which contain a fluid medium designed to absorb shock and support and cushion the foot. The following are examples of various prior art.

[0005] U.S. Patents 4,183,156, 4,219,945, and 4,340,626 disclose the use of resilient fluid bladders as midsole special cushioning elements.

[0006] U.S. Patents 4,342,157 and 4,472,890 disclose liquid filled shock absorbing cushions in the heel portion and the forefoot portion of a shoe. The liquids include water, glycerine, mineral oil, or other suitable low viscosity liquids.

[0007] U.S. Patent 5,493,792 discloses a shoe with a sole portion and at least one cushioning element including a chamber having flexible walls filled with a liquid composition. The liquid composition preferably includes an amount of gel having a gel density and an amount of particulate having a particulate density wherein the particulate density is less than the gel density. However, in this patent the particulate slows the movement of the gel between partitioned sections within the chamber. The particulate also takes on an aesthetic role as it may be viewed through the cushioning element as the cushioning element has transparent walls.

[0008] U.S. Patent 6,266,897 discloses a ground contacting system including 3D deformation elements having interiors filled with a compressible fluid or other materials such as liquids, foams, viscous materials,

and/or viscoelastic materials. The 3D deformation elements decrease the amount of force transferred to the wearer due to their ability to deform, distort, or deflect three dimensionally.

[0009] The conventional shoes are problematic in providing adequate support, comfort, and shock absorption. Therefore, there is a need in the industry for a cushioning device for a footwear or shoe which includes a magnetic fluid for absorbing and dampening vibrations and shocks.

OBJECTS AND SUMMARY OF THE INVENTION

[0010] The principal object of the present invention is to provide a cushioning device for a footwear or shoe which includes a magnetically responsive fluid, and a magnet member for applying a magnetic field to the fluid for varying the viscosity thereof. The fluid functions as a shock absorbing fluid, and has a relatively high viscosity. Preferably, the viscosity of the fluid, even when not acted upon by a magnetic field, is greater than the viscosity of water, glycerine, hydraulic oil, and/or mineral oil.

[0011] An object of the present invention is to provide a cushioning device for a footwear or shoe which includes a magnetically responsive fluid. The magnetically responsive fluid includes a particulate

matter which gives the fluid magnetic and rheological properties so that the fluid may absorb and/or dampen shocks and/or vibrations upon the application of a magnetic field.

[0012] Another object of the present invention is to provide a cushioning device for a footwear or shoe which includes a magnetically responsive fluid. The magnetically responsive fluid remains substantially rigid in order to absorb and/or dampen shocks and/or vibrations.

[0013] Still yet another object of the present invention is to provide a cushioning device for a footwear or shoe sole which includes a weight sensor, a movement sensor, a control unit, an electromagnet, a lithium ion battery, and a magnetic fluid. The shoe sole includes at least one cavity filled with a magnetic fluid and an electromagnet. The electromagnet applies a magnetic field to the magnetic fluid such that the magnetic fluid absorbs and/or dampens shocks and/or vibrations before they are transferred to the wearer's foot.

[0014] An additional object of the present invention is to provide a cushioning device for a footwear or shoe sole which includes a magnetic fluid and a device capable of generating a magnetic field that will cushion the wearer's foot and provide comfort and support for the wearer.

[0015] Yet an additional object of the present invention is to provide a cushioning device for a footwear or shoe sole which includes a fluid that is magnetically responsive and exhibits rheological changes upon interaction with a magnetic field generated by a device capable of generating a magnetic field.

[0016] Still yet an additional object of the present invention is to provide a cushioning device for a footwear or shoe sole which includes a fluid that is magnetically responsive and exhibits rheological changes upon interaction with a magnetic field generated by at least one electromagnet.

[0017] In summary, the main object of the present invention is to provide a cushioning device for a footwear or shoe which uses a magnetically responsive fluid to absorb and/or dampen shocks and/or vibrations to cushion the wearer's foot thereby providing comfort and support for the wearer.

[0018] At least one of the above-noted objects is met, in part, by the present invention, which in one aspect includes a cushioning device for a footwear including a chamber with a magnetically responsive fluid, and a magnetic member for applying a magnetic field to the fluid thereby varying the viscosity thereof.

[0019] Another aspect of the present invention includes a sole for a footwear including a chamber with a magnetically responsive fluid, a magnetic member for applying a magnetic field to the fluid thereby varying the viscosity thereof, and a control unit for relaying a signal to the magnetic member to apply a magnetic field.

[0020] Another aspect of the present invention includes a sole for a footwear including a chamber with a magnetically responsive fluid, an electromagnet for applying a magnetic field to the fluid thereby varying the viscosity thereof, a movement sensor for determining the movement of a footwear, a weight sensor for determining the weight of a user of a footwear, and a control unit for receiving information from one of the movement and weight sensors and relaying a control signal to the electromagnet for applying a magnetic field.

[0021] Another aspect of the present invention includes a method of varying the shock absorbing capacity of a footwear cushioning device, including providing a cushioning device comprising a chamber including a magnetically responsive fluid, and a magnetic member for applying a magnetic field to the fluid, applying a magnetic field to the fluid based on an input to

thereby vary the viscosity of the fluid, and whereby a change in viscosity of the magnetic fluid changes the shock absorbing capacity of the cushioning device.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The above and other objects, novel features and advantages of the present invention will become apparent from the following detailed description of the preferred embodiment(s) of the invention, as illustrated in the drawings, in which:

[0023] Figure 1 is a schematic illustration of a footwear sole incorporating a cushioning device in accordance with the present invention;

[0024] Figure 2 is a schematic illustration of a partial, enlarged portion of the toe cavity showing the conformation of the magnetic particles in the fluid not exposed to a magnetic field;

[0025] Figure 3 is a view similar to Figure 2, showing the conformation of the magnetic particles in the fluid exposed to a strong magnetic field;

[0026] Figure 4 is a view similar to Figure 2, showing the conformation of the magnetic particles in the fluid exposed to an intermediate magnetic field;

[0027] Figure 5 shows force versus displacement hysteresis cycles at 0-2 A for magnetic fluid with 60% solids loading of iron oxide nanoparticles with an average diameter between 45-50 nm, lecithin as the surfactant, and Mobil DTE 20 series hydraulic oil as the carrier liquid; and

[0028] Figure 6 illustrates various shapes of the magnetic particles for use in the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S) OF THE INVENTION

[0029] It is noted initially that the term "shoe", as used herein, broadly includes all types of footwear including, for example, slippers, sandals, and casual, sports and dress shoes.

[0030] Figure 1 illustrates a cushioning device CD incorporated in a footwear sole S. As shown, the cushioning device CD includes a magnetic fluid 10 incorporated in a toe cavity 12 (and/or a heel cavity 14). The

toe and heel cavities 12 and 14 include magnetic elements, such as electromagnets 16 and 18, respectively. Preferably, the electromagnet 16 (and/or electromagnet 18) extends above and below the toe cavity 12 (and/or heel cavity 14) (Figure 2), as one integral piece, but may alternatively be provided as two separate members. (It is noted herewith that while both toe and heel cavities 12 and 14 are illustrated herein to contain the magnetic fluid 10, only one is necessary for the cushioning device CD of the present invention.)

[0031] The cushioning device CD further includes a weight sensor 20, a movement sensor 22, a control unit 24, and a source of electrical power, such as a lithium ion battery 26. The magnetic fluid 10 includes magnetic particles 28 dispersed in a carrier fluid 30.

[0032] The weight sensor 20 detects the weight of a wearer and determines the force the wearer exerts upon the ground, while the movement sensor 22 detects the wearer's movement. The movement sensor 22 can distinguish between various types of movement or activities, such as running, jogging, jumping, stepping, skipping, brisk walking, slow walking, etc. The data from the weight sensor 20 and the movement sensor 22 is transmitted to the control unit 24, which combines the data to determine an appropriate

resistive force and the amount and direction of the magnetic field necessary to generate that resistive force in the magnetic fluid 10.

[0033] The control unit 24 relays a time varying current signal to the electromagnet 16 (and/or 18), which generates the amount of magnetic field in a particular direction (preferably generally vertically relative to a generally horizontal support surface) necessary for the magnetic fluid 10 to generate the appropriate resistive force. A stronger magnetic field gives a greater resistive force, while a weaker magnetic field gives a weaker resistive force. The resistive force generated by magnetic fluids in the presence of an applied magnetic field has been thoroughly investigated and are observed to be dependent upon the magnetic susceptibility, applied field strength, saturation magnetism and the particle volume. Dipolar interactions between the particles causes them to align into chains with a coupling constant λ defined by the following equation:

$$\lambda = f\ (\mu, a3, H, \chi)$$

where μ is the magnetic permeability, a is the particle radius, H is the magnetic field strength, and χ is the particle susceptibility. The higher is the particle susceptibility, faster is the response time to varying magnetic field.

Depending upon the sample confinement, the rate of applied magnetic field and the particle concentration, the particles coalesce together to form either separated columns or chains, or 'bent-wall' like structures. These field-induced structures give rise to an anisotropic rheological response exhibiting an increase in viscosity normal to the direction of the applied field with certain resistive force. With respect to direction, a magnetic field applied in a direction such that chains of magnetic particles are formed generally perpendicular to a horizontally oriented ground gives a greater resistive force than a magnetic field applied in a direction that causes chains of magnetic particles to form parallel to a horizontally oriented ground. Upon application of a magnetic field by the electromagnet 16 (and/or 18), the particles 28 within the magnetic fluid 10 magnetically couple to form preferably generally vertically oriented, generally rectilinear chains and/or bent-wall like structures 32 and 34 (Figures 3 and 4), which creates a yield stress. Therefore, upon application of a magnetic field by the electromagnet 16 (and/or 18), the magnetic fluid 10 becomes more resistive and capable of absorbing shocks and/or vibrations.

[0034] If the control unit 24 determines from the weight and movement data that no resistive force is necessary, the control unit 24 relays a time varying current signal to the electromagnet 16 (and/or 18) indicating that no magnetic field is necessary. For example, when a person is not wearing the shoe, there is zero weight and zero movement, and the magnetic field remains

in the off position. (However, when a load is put on the shoe and a movement is detected by the movement sensor 22, the magnetic field is triggered to provide an optimal resistive force.) As illustrated in Figure 2, the electromagnet 16 (and/or 18) does not generate a magnetic field and the magnetic particles 28 within the magnetic fluid 10 remain freely suspended.

[0035] If the control unit 24 determines from the weight and movement data that a maximum resistive force is necessary, the control unit 24 relays a time varying current signal to the electromagnet 16 (and/or 18) indicating that a maximum magnetic field is necessary. As illustrated in Figure 3, the electromagnet 16 (and/or 18) generates a maximum magnetic field and the magnetic particles 28 within the magnetic fluid 10 magnetically couple to form generally straight chains and/or bent-wall like structures 32.

[0036] If the control unit 24 determines from the weight and movement data that an intermediate resistive force is necessary, the control unit 24 relays a time varying current signal to the electromagnet 16 (and/or 18) indicating that an intermediate magnetic field is necessary. As illustrated in Figure 4, the electromagnet 16 (and/or 18) generates an intermediate magnetic field and some of the magnetic particles 28 within the magnetic fluid 10 remain freely suspended, while the other magnetic particles 28 within the

magnetic fluid 10 magnetically couple to form shorter chains or bent wall-like structures 34.

[0037] In addition to varying the strengths of a magnetic field applied by the electromagnet 16 (and/or 18), the control unit 24 also has the capacity to relay signals to electromagnets 16 and 18 individually, substantially simultaneously, or at different times. This feature becomes important and desirable when one movement/activity over another is selected by the wearer. For instance, if the footwear is being used in running or jogging, it may be desirable to have an increased resistive force in the heel area, as opposed to the toe area. Likewise, it may be desirable to have the same level of resistive force in both the heel and toe areas, in the event a footwear is used for casual walking. The control unit 24 may therefore be programmed to relay appropriate signals to one or both electromagnets 16 and 18, as desired.

[0038] Preferably, the movement sensor 22 is also capable of detecting surface conditions, and the control unit 24 incorporates the surface condition data with the weight and movement data when determining the necessary resistive force.

[0039] The sensors 20 and 22, control unit 24, and the electromagnet 16 (and/or 18) are powered by a source of electrical power,

such as the rechargeable Li-ion battery 26. Rechargeable Li-ion battery 26 is the preferred power source as it is compact, lightweight, and has a high power density. It produces power for approximately two days until it needs recharging depending upon the wearer's level of activity.

[0040] It is noted herewith that the resistive force generated by the formation of chain or bent-wall like structures in the magnetic fluid 10, is reversible, and not permanent. The force preferably lasts only as long as the magnetic field is present. Once the magnetic field is removed or is no longer present, the magnetic particles decouple and become freely suspended again in the magnetic fluid 10.

[0041] The particles 28 in the magnetic fluid 10 may be synthesized by various methods, such as chemical synthesis, sol-gel, chemical co-precipitation and microwave plasma technique. The microwave plasma technique, described in U.S. Patent 6,409,851 by Sethuram et al. (incorporated herein in its entirety by reference) is the preferred technique as it is unique in that it gives better control over particle size, shape and purity, and can be readily extended to produce different compositions of powders. The magnetic fluid 10 includes a carrier medium 30 and a particulate material comprised of particles 28. The particulate material is preferably made of iron, iron oxide, cobalt, cobalt oxide, nickel, nickel oxide, an alloy such as steel, or a

combination thereof. Preferably, the particulate material is made of iron, iron oxide, or a combination thereof.

[0042] The average diameter or size of the particles can be from about 1 nm to 100 μm. The preferred size is about 1 nm to 10 μm, while the most preferred size is about 10 nm to 5 μm. The size of the particles partially determines the magnetic character of the magnetic fluid and the maximum yield stress attainable. Larger particles give the magnetic fluid a greater magnetic character and a larger maximum yield stress, while smaller particles give the magnetic fluid a smaller magnetic character and a smaller maximum yield stress. A particle mixture of more than one particle size may be used to obtain a desired magnetic response.

[0043] The shape of the particles is important for two reasons. First, the magnetic effect is dependent upon the particle volume fraction, which in turn is a function of the particle shape. For instance, needle-shaped particles exhibit similar magnetic effect at concentrations ten times smaller than spherical particles because of larger surface area per volume. Second, the flow characteristics of the particles in a liquid medium are dependent upon their shape. The shapes utilized in this invention include, but are not limited to, spherical, needle-like, cubic, irregular, cylindrical, diamond, oval, or a combination thereof (Figure 6).

[0044] Preferably, the particulate volume or weight fraction is about 1-95%. A greater particulate volume or weight fraction results in an enhanced magnetic character and a greater maximum yield stress. However, if the particulate volume or weight fraction is too large, the zero field viscosity is too great and the magnetic fluid loses fluidity when no magnetic field is applied. The term zero field viscosity refers to the viscosity of the magnetic fluid when no magnetic field acts upon the magnetic fluid.

[0045] In the present invention, the surface coating on the particles serves several purposes, including preventing particle agglomeration and preventing dissolution of the magnetic materials.

[0046] Colloidal particles have an inherent tendency to aggregate and form clusters or agglomerate due to attractive van der Waals (vdW) forces. To stabilize the particles against these attractive forces, it is necessary to introduce a repulsive interparticle force, either by an electrostatic or by a steric means. Electrostatic stabilization utilizes the surface charge typically present on the particles, which is effective in a medium having a high dielectric constant, such as water, while in steric stabilization, a sufficiently thick layer of a polymeric or surfactant molecules is introduced around the particles. The surface layer functions as a steric barrier to prevent particle agglomeration,

and thereby ensures stability of the fluid. The surface layer also prevents dissolution of the magnetic materials. This technique is preferred for the present invention. The particles are preferably coated with a surfactant and/or coating by adsorption of surfactant and/or coating molecules onto the particles in the presence of ultrasonic irradiation in a high shear field. The types of surfactants that may be utilized in the present invention include, but are not limited to, polyethylene glycol, lecithin, oleic acid, or Surfynol® surfactants (available from Air Products). The types of coatings that may be utilized in the present invention include, but are not limited to, silica, gold, silver, platinum, steel, cobalt, carbon, a polymer, or a combination thereof. The polymer can be one of polyethylene glycol, polystyrene, dextran, or a combination thereof. Preferably, the particles are only coated with lecithin or Surfynol® surfactants (available from Air Products).

[0047] The magnetic particles coated with a surfactant are dispersed in a carrier liquid by high shear mixing followed by ultrasonification to form a homogenous fluid. The carrier liquid helps to retain the fluidity of the magnetic fluid when the magnetic fluid is not acted upon by a magnetic field. It is also important as it partially determines the effective fluid viscosity. Carrier liquids are preferably water based and oil based liquids, such as glycerol/water, and/or mineral oil mixtures. Preferably, the carrier liquid is

water, hydraulic oil, mineral oil, silicone oil, biodegradable oils, or a combination thereof.

EXAMPLE

[0048] Ultrafine powders of iron oxide with an average particle size of about 45-50 nm were produced using the proprietary microwave plasma chemical synthesis process described in U.S. Patent 6,409,851 by Sethuram et al. Vapors of iron pentacarbonyl were fed into the plasmatron with argon/oxygen as the plasma gas. The plasma gas flow rate was about 0.003-0.0034 m^3/min and that of the carrier gas was about 0.0003-0.0004 m^3/min. The plasma temperature was about 900-950° C, the powder feed rate was about 50-60 gm/hr, and the quenching water flow rate was about 2.0-2.5 liter/min at about 20° C. The reactor column diameter was about 48 mm and its length was about 10". The microwave forward power was about 4 kW, the reflected power was about 0.7 kW, and the operating frequency was about 2450 MHZ.

[0049] Standard magnetic characterization of temperature dependent susceptibility and M-H hysteresis loops were performed using a variable temperature range of about 5 K to 350 K and magnetic fields of about 0 T – 5 T. The magnetic characterization tests were performed using

Magnetic Property Measurement Systems from Quantum Design that uses SQUID magnetometry. The coercivity of the iron oxide nanopowders was about 176 Oe and the magnetic saturation was about 40 emu/g.

[0050] Lecithin (about 2 wt% - optimized) was mixed in Mobil DTE 20 series hydraulic oil using a high speed emulsifier at speeds close to 11,000 rpm. The iron oxide nanopowders were added the oil and the mixing continued. The mixing speed was kept constant at about 11,000 rpm for a mixing time of about 30 minutes. The solids loading was about 60 wt%.

[0051] Force versus displacement hysteresis cycles at 0-2 A were generated using an unpressurized Rheonetics truck seat damper (available from Lord Corporation, Cary, NC). The force versus displacement hysteresis cycles are shown in Figure 5.

[0052] While this invention has been described as having preferred sequences, ranges, steps, materials, features, or designs, it is understood that it is capable of further modifications, uses and/or adaptations of the invention following in general the principle of the invention, and including such departures from the present disclosure as those come within the known or customary practice in the art to which the invention pertains, and

as may be applied to the central features hereinbefore set forth, and fall within the scope of the invention and of the limits of the appended claims.